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Impact of Scallop Harvesting on Eelgrass (*Zostera marina*) Meadows: Implications for Management

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ABSTRACT

Eelgrass (*Zostera marina*), an important component of estuarine areas from Nova Scotia to North Carolina, is the primary habitat for the economically important bay scallop (*Argopecten irradians*). The bay scallop fishery in North Carolina is extensive yet precarious in its dependence on seagrass systems. A balance between habitat integrity and scallop harvest is necessary to sustain the fishery. In this study, we examined the effect of scallop dredging on eelgrass meadows. When the eelgrass was in its vegetative stage, 15 and 30 dredgings were carried out in a hard sand substrate and a soft mud substrate and the results compared to an area of no dredging. Impact was assessed by analyzing the effects of scallop harvesting on eelgrass foliar dry weight and on the number of shoots. The hard bottom had significantly greater overall biomass of eelgrass ($P < 0.01$, ANOVA) than the soft bottom but fewer differences were apparent for eelgrass shoot density ($P < 0.10$). Increased dredging led to significantly reduced levels of eelgrass biomass and shoot number ($P < 0.01$) on both hard and soft bottoms. Harvesting of bay scallops in North Carolina occurs at a time of seasonally low eelgrass foliar biomass, peak abundance of commercially harvestable scallops, and settlement of post-larval scallops that require eelgrass leaves for attachment. Our data demonstrated potentially negative impacts on the scallop fishery that would result from harvest-related damage to existing eelgrass meadows.

The importance of eelgrass systems to the ecology of the nearshore coastal zone has been widely recognized (e.g., Thayer et al. 1975a, 1975b, 1979; Zieman 1975a, 1975b; Thayer and Phillips 1977; Fonseca et al. 1979; McRoy and Helfferich 1980; Ferguson et al. 1981), and information on the role of these habitats as nursery areas for many fish species is now being documented extensively (e.g., Adams 1976; Thayer et al. 1979; Weinstein and Heck 1979; Heck and Orth 1980; Miller and Dunn 1980; Stoner 1980; Homziak et al. 1982; Homziak et al., in a paper entitled "Settlement of the bay scallop [*Argopecten irradians*] and the hard clam [*Mercenaria mercenaria*] in an artificially established eelgrass [*Zostera marina*] meadow" in preparation). Eelgrass (*Zostera marina*) is restricted to shallow, subtidal areas primarily because of light requirements and, therefore, is subject to many stresses imposed by man (Thayer et al. 1975b).

A potential impact on eelgrass systems that is not widely recognized, but that can have far-reaching effects, stems from the commercial harvest of the bay scallop (*Argopecten irradians*). The principal commercial gear in North Carolina is a heavy epibenthic dredge (22.7 kg legal limit) pulled by a power boat. Common recreational and small-scale commercial harvesting is done by hand collecting, hand-pulled dredges, and raking. Because scallops are found in commercially valuable quantities almost exclusively in eelgrass meadows (Thayer and Stuart 1974; Spitsbergen 1979), damage to the meadows also may reduce the future numbers of scallops. Thayer and Stuart (1974) demonstrated that commercial dredging reduced both scallop and eelgrass density in an area near Beaufort, North Carolina, and Fonseca et al. (1979) described mitigative measures to reestablish an eelgrass bed

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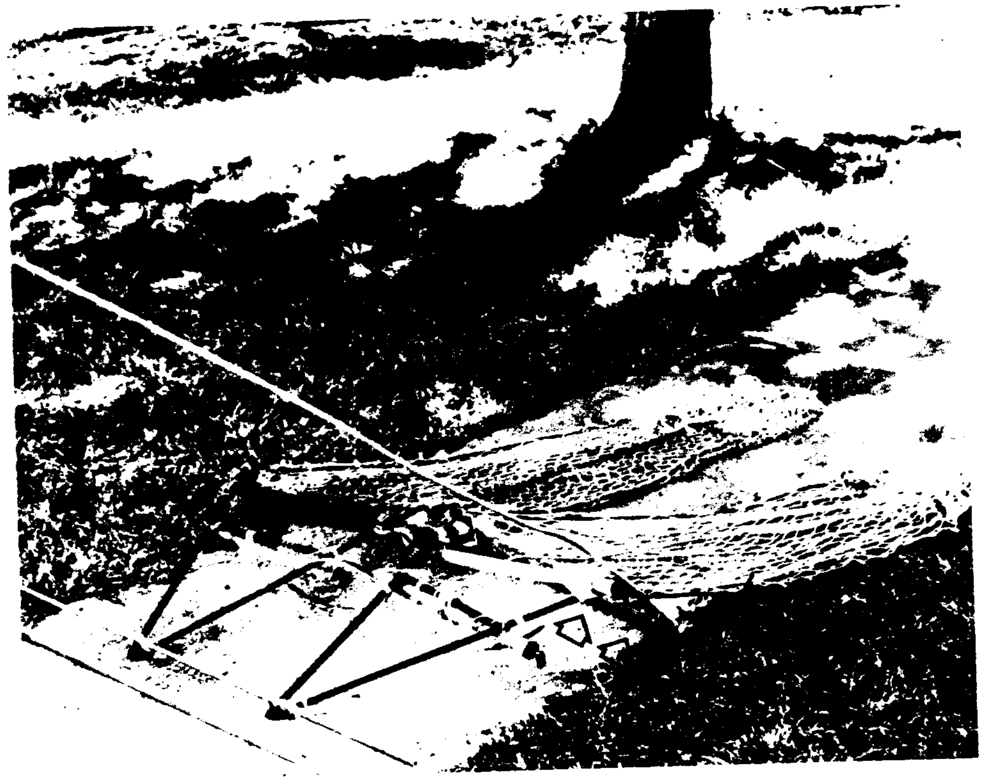

Figure 1. Two scallop dredges, linked side by side, used in this study. Note the lack of teeth (arrow) on the dredge foot. The vertical rod was added to guide the dredge unit over the impact site.

that had been denuded by commercial scalloping. These authors described two areas that sustained a harvesting impact, but they did not describe the mechanism of impact other than it uprooted the eelgrass shoots. In this paper, we describe the impact of scallop harvesting on the eelgrass population itself.

Our concern over the destruction of eelgrass habitat is based on an expected reduction in local primary productivity, in detritus production (Fonseca et al. 1982), and in seedling production. All of these factors contribute to the maintenance of eelgrass meadows. Increased erosion of subtidal areas (Fonseca et al. 1982) and losses of the associated faunal community (Homziak et al. 1982; Homziak et al. in preparation) also may follow removal of the eelgrass shoots. We recognize the need to balance habitat protection with maintenance of the scallop fishery (Spitsbergen 1979) but this balance is not easy to accomplish or maintain. Controls now exerted on the fishery in North Carolina regulate collecting techniques for scallops, quantity collected, season, and geographic areas open to the fishery, but there is presently no information that can contribute to objective decisions on the selection of habitats open to scalloping. If scallop harvesting were denied in nursery areas (North Carolina Fishing Regulations for Coastal Water, 1982, Subchapter 3B, Sec. 1402), the scallop fishery would be eliminated because all eelgrass beds are nursery areas for finfish and crustaceans. Obviously, additional criteria are needed for determining the scope of preservation and protection of the eelgrass habitat to maintain a viable bay scallop industry.

Area and Methods

Two study sites located in Back Sound near Beaufort, North Carolina were dredged on March 8 and 9, 1982. One is a hard-bottom area and the other a soft-bottom area. The contrast al-

Figure 2. Hand-pulled scallop dredging in the shallows of Snead's Ferry, North Carolina (courtesy of James Tyler, North Carolina Division of Marine Fisheries).

lowed the impact of dredging to be examined on two disparate types of habitat colonized by eelgrass in the Beaufort area. The first site is exposed to a several-mile fetch of prevailing southwest winds. Sediments are compacted and had 19.8% silt and clay (S-C) and 5.2% organic matter (OM, combustion at 500 C for 12 hours) in the upper 3 cm of sediment. The sediment was dominated by sand at depths down to 20 cm (S-C = 5.17%, OM = 1.21%). The second site was in a protected passage between an island and the mainland. These sediments were less compact and had higher silt-clay (22.3%) and lower organic matter content (2.6%), and these percentages were quite constant through the 20-cm profile.

Commercial scallop dredges were used (Fig. 1), each weighing 13 kg and measuring 65 cm across. The dredge weight, however, was only about 60% of the legal limit. Sampling areas that contained few scallops were purposely selected so that dredge weight during each experiment could be held virtually constant. Two dredges were linked side by side (Fig. 1) to expand the impact area. Each dredge could swing independently, allowing it to respond individually to the bottom contour. As is sometimes done by commercial workers, the dredges were pulled by hand rather than by a boat (Fig. 2), but with ropes from outside the study area. Hand dredging was done to eliminate propeller scour which commonly occurs during harvesting in shallow meadows. Thus, our experiment was designed solely to evaluate the impact of an empty scallop dredge. In commercial scalloping, the added scallop weight and the propeller wash could be expected to have a greater impact.

Within roughly a 100-m diameter circle in each study site, nine arbitrarily located quadrats (1.05 × 1.95 m) were marked off. The meadows were not clearly visible, due to high water turbidity, and the selection of eelgrass cover also was arbitrary. Of the nine quadrats per habitat, three were assigned randomly for no dredging, another three were assigned 15 dredgings, and the final three were assigned 30 dredgings. A single dredging consisted of placing the dredges about

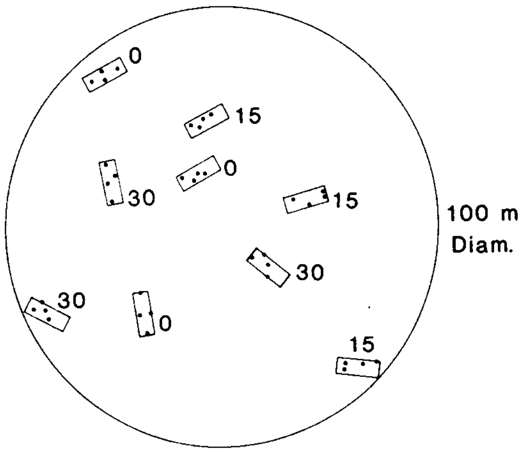

Figure 3. Within a 100-meter diameter area (not to scale) in each habitat type, nine quadrats representing three levels of dredging effort (0, 15, and 30 dredgings) were arbitrarily located and randomly assigned a dredging level. Each quadrat had four randomly selected cores taken for eelgrass foliar biomass and shoot counts, as shown in each quadrat.

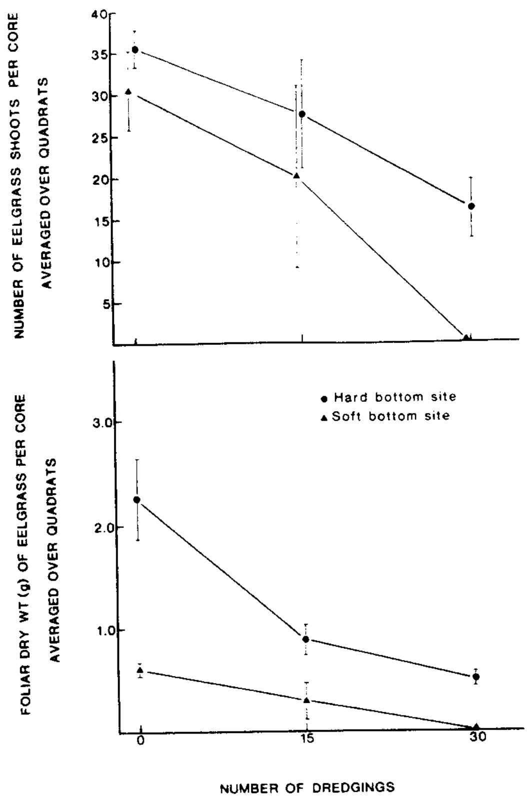

Figure 4. Upper panel shows the decrease in shoot number per core; lower panel, decrease in foliar biomass (grams dry weight) per core. Both are averaged over quadrats on each of the two bottom types. Vertical bars around means represent one standard error and, where bars overlap, the values are offset for readability. Circles = hard bottom site; triangles = soft bottom sites.

1 m from the end of a quadrat, passing the tow rope around the quadrat, then pulling the dredge over it. Pulling speed was approximately 2 knots (similar to vessel towing speed) and was continued until the entire dredge was clear of the study area. At the edge of the quadrat, the dredge was turned around and the process was repeated for a second dredging, etc.

Each quadrat was marked off in a grid pattern. Grid intersections were assigned numbers, and locations for core samples of the grasses were selected randomly by consulting a table of random numbers (Fig. 3). To determine eelgrass foliar biomass and shoot counts, four cores 15 cm in diameter were taken in each quadrat after the dredging was completed. No coring occurred within 5 cm of another. Undredged quadrats were the controls. Care was taken before inserting each core to prevent eelgrass shoots from being sliced by the core tube; only whole shoots were removed in the cores. Foliar portions of eelgrass shoots from each core were removed, counted, and dried to a constant weight at 90 C.

The data were analyzed as a factorial treatment design with two habitat types and three levels of dredging effort. Within habitat-dredging level combinations, replicate quadrats provided the estimate of experimental error required to test main effects and interactions. Subsampled cores allowed an estimate of variance within individual quadrats (sampling error).

Thirty dredgings per day was considered to be a reasonable maximum number based on our field observations of fishing effort. These observations indicated that at some sites, given a random pattern of dredging, each square meter of eelgrass bed had a probability of being dredged 0.8 time per fishing day. Given the fact that fishermen do not dredge randomly but concentrate

Table 1. Analysis of variance for eelgrass shoot number by habitat type and dredging effort.

Source of variation	df	SS	MS	F	Significance
Habitat	1	1,624.50	1,624.50	4.01	0.068 n.s.
Dredgings	2	7,650.58	3,825.29	9.44	0.003**
Linear	1	7,475.02	7,475.02	18.45	0.001**
Quadratic	1	175.56	175.56	0.43	0.524 n.s.
H × D (Interaction)	2	379.75	189.88	0.47	0.636 n.s.
Experimental error (quadrats within treatments)	12	4,862.67	405.22	2.18	0.026*
Sampling error	54	10,026.00	185.67		

fishing effort on portions of the fishing ground that yield better harvest, it is conceivable that a given square meter could be dredged up to 30 times in a day.

Results

A decrease in both the number of eelgrass shoots and foliar dry weight occurred with increasing dredging effort for each bottom type (Fig. 4). Analysis of variance (ANOVA) of shoot number (Table 1) and foliar dry weight per core (Table 2) indicated that the experimental error (among-quadrat variation) was greater than the sampling error (within-quadrat variation), a result consistent with the patchy distribution of eelgrass. We found significant differences in variance within habitat-dredge combinations (i.e., at soft bottom sites, variances approached zero after 30 dredgings) that could not be stabilized by commonly applied transformations. Therefore, we did not transform the data but, following ANOVA, we constructed a conservative error term by eliminating the effect of the soft bottom-30 dredge combination (by reducing the degrees of freedom from 12 to 10). The resulting tests did not alter our initial conclusions. For number of shoots, no significant interaction of bottom type and dredging level was detected, indicating that the effect of dredging did not vary with habitat. Overall, there was a significant decline in shoot numbers with dredging effort and the relation was linear. Numbers of shoots were not significantly different by bottom type but the significance level ($P = 0.068$) was a cause for suspicion. This nearly significant effect of bottom type probably was due to the complete removal of shoots from the soft bottom at 30 dredgings. There were no differences between bottom types at 0 and 15 dredgings, as evidenced by overlapping error bars (Fig. 4).

For foliar dry weight per core, the experimental error for among-quadrat variation also was significantly greater than sampling error for within-quadrat variation (ANOVA, Table 2). There was, however, a significant habitat-dredge interaction ($P < 0.05$), reflecting the greater loss of foliar biomass from the hard bottom between the 0 and 15 dredgings (Fig. 4). This reduction for hard-bottom sites may have been caused by a selective removal of older, larger shoots and leaves. The existence of these larger shoots was evidenced by higher biomass per shoot in the hard-bottom controls (Fig. 4, divide weight per core by number of shoots per core). Although both shoot number and foliar dry weight were reduced to zero at the soft-bottom sites, hard-bottom sites lost a quantitatively larger amount of biomass due, at least in part, to their higher initial biomass. The effect of dredging on biomass again was best described as a linearly decreasing function.

Discussion

Our data demonstrated the negative impact of scallop dredging on the eelgrass in primary nursery areas for scallops. Changes in foliar dry weight are a better indicator of short-term dredging effects than changes in shoot abundance because dry weight more accurately describes the amount of plant material a dredge encounters and implicitly accounts for the size of shoots, which shoot number alone does not do. Shoot loss may cause a long-term habitat degradation (1–2 years) but leaf removal presents an immediate reduction in scallop larvae settlement and refuge sites independent of shoot recovery. Foliar dry weight measurements seem more sensitive to trends that were only marginally supportable by data on shoot number.

The soft-bottom area we studied was more

Table 2. Analysis of variance for eelgrass dry weight by habitat type and dredging effort.

Source of variation	df	SS	MS	F	Significance
Habitat	1	15.1235	15.1235	35.99	0.000**
Dredgings	2	17.6499	8.8249	21.00	0.000**
Linear	1	16.6222	16.6222	39.56	0.000**
Quadratic	1	1.0277	1.0277	2.45	0.144 n.s.
H × D (Interaction)	2	4.8620	2.4310	5.78	0.017*
Experimental error (quadrats within treatments)	12	5.0427	0.4202	3.60	0.001**
Sampling error	54	6.3033	0.1167		

susceptible than hard bottom to dredging damage, as measured by a proportional reduction in shoot number (nearly significant and therefore suspect) and dry weight. Two sites having similar numbers of shoots were affected very differently by 30 dredgings; on the soft bottom, all shoots were removed, but on hard bottom about 15 per core remained. Although shoot density on the soft bottom was initially the same as on the hard bottom, the biomass on an areal basis was 75% lower (Fig. 4).

Lower initial biomass (smaller average shoot size) could be a factor in the total removal of eelgrass cover from the soft bottom. Another factor may be the relative integrity of shoot attachment in the sediment between habitat types. In the hard bottom, root mass and root/shoot ratios generally are greater (Kenworthy 1981; Kenworthy et al. 1982) suggesting that eelgrass is more firmly attached there than in the soft bottom. We cannot predict that a greater amount of shoot and/or foliar weight loss would have occurred had the hard bottom had less initial biomass (perhaps expressed as smaller shoots). Intuitively, we suspect the integrity of attachment in the hard bottom may be the more important of the two factors (areal foliar weight and bottom types) in resisting dredge effects. Shoot size is controlled largely by age as well as by available light, a function of depth, and less directly correlated with bottom type. If shoots in the hard bottom are torn off and the meristem/root-rhizome system is left intact, the opportunity for shoot regeneration may be greater than in soft bottom, where we might expect the whole plant (with meristem, roots, and rhizomes attached) to be uprooted.

The reduction in leaf surface area through leaf breakage and whole shoot removal could pose immediate problems for epibiotic organisms, including post-larval bay scallops, which require an attachment surface above the bottom—presumably to escape predation (Thayer et al. 1979). The importance of the epibiota as a food resource for economically and ecologically important estuarine organisms has been discussed by Thayer et al. (1975a, 1975b, 1979) and others cited therein. Gutsell (1930) and Spitsbergen (1979) pointed out that scallops associated with eelgrass beds are dominated by two size classes during early winter: commercially harvestable and early-juvenile classes. The latter, 0–10 mm shell height, are found almost exclusively attached to the blades of grass, the peak season of occurrence being March and April (Spitsbergen 1979). Spitsbergen (1979) noted that the maximum meat : shell ratio for harvestable scallops occurs in January and February. Thus, the optimal period of scallop harvest, as judged by meat : shell ratios, closely coincides with the time of near-maximum attachment requirements of early juveniles. The entire harvest period in North Carolina (December–May) coincides with the time of low eelgrass density, and standing-crop values of less than 50 g dry weight/m^2 are common (Kenworthy 1981). Both of these factors were shown here to be inversely correlated with dredging.

Seedling germination and sexual reproduction of eelgrass in North Carolina also occur during December through March, the period of commercial scallop harvest. Seedlings represent an aspect of eelgrass meadow perpetuation that is not well understood. We theorize that if eelgrass beds geographically isolated from seedling input from other meadows are heavily dredged, any reduction in reproductive structures and germinating seedlings may adversely affect the continuation and/or recovery of that meadow. Even areas of high seedling density will fall at the low end of the range of standing crop and surface area, and should be more susceptible than proportionately larger, mature shoots to damage by commercial scalloping.

The time of peak shell : meat ratio, juvenile attachment to grass blades, low eelgrass biomass, and peak harvest efforts occur almost simultaneously. The lower eelgrass biomass and higher scallop meat : shell ratio benefits fishermen by respectively reducing fishing effort through less grass interference and by increasing the volume of saleable meat per unit catch. However, we hypothesize that the settlement and growth of juvenile scallops as well as sexual and vegetative reproduction of the eelgrass meadow may be severely hindered by dredging. Eelgrass growth is relatively slow during the scallop season. Recovery of any damaged shoots would not occur in time to provide attachment surfaces for scallop larvae. New shoots also would not be produced in sufficient numbers to meet the attachment needs of the scallops in this 3–4 month period, especially because dredging is a continuing process.

Isolated eelgrass meadows that have been severely damaged can be restored at a low cost (Fonseca et al. 1981, 1982) if natural means of recovery prove inadequate. Natural recovery rates of shoots, however, are slow even in areas with adjacent seed sources and viable grass beds (Fonseca et al. 1979; Kenworthy et al. 1980; Fonseca et al. 1982). The loss of an eelgrass meadow should be avoided in any event, not only because of the initial loss of habitat for fishery organisms but also because unmitigated losses can persist for at least 2 years from the onset of dredging activities or physical perturbation (Homziak et al. 1981; Stuart 1982).

A balanced bay scallop fishery consists of preserving the integrity of scallop habitat while minimizing its degradation. Our data support the recommendation of Thayer and Stuart (1974) for harvest rotation to minimize habitat impact.

We conclude that intensive scallop dredging has the potential for immediate as well as a long-term reduction of the eelgrass nursery habitat. This conclusion is based on observations of biological damage to the eelgrass which reduces the surfaces of attachment for early stage juvenile scallops and other invertebrates. The dredges we used had no additional weights (legal maximum, 22.7 kg), no scallops in the tailbags, and there was no propeller scour; hence, the effects were minimal.

Methods of impact assessment should include monitoring shoot biomass in geographically isolated eelgrass beds, especially in soft-bottom habitats, to determine the scale of impact to the meadows. Now it must be determined if the actual loss of eelgrass habitat from dredging causes a measurable reduction in the bay scallop and other fishery yields.

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